Packing and transport

It will be the responsibility of the manufacturer to arrange for safe and efficient transport and delivery of the magnets to CERN.

Provisional acceptance

Each magnet will be excited at full field and tested magnetically at CERN. Should these tests reveal any defects due to faulty construction, damage during transport, or failure of the magnet to meet the specified mechanical tolerances and electrical tests, CERN will be entitled to the urgent repair or replacement of the faulty part(s) free of charge.

Late deliveries

The quadrupole manufacturer shall closely follow the delivery profile which will be stipulated in the contract so as not to perturb the subsequent operations on the quadrupoles at CERN. A tolerance of plus or minus one month of production (9 quadrupoles) with respect to this profile will be accepted. The manufacturer must not deliver magnets above the maximum limit. For quadrupoles delivered below the minimum limit, the penalties stipulated in Section 10 of the Tender Form will be applied.

2. MANUFACTURE OF THE MAGNETIC CIRCUIT

The steel sheet

The laminations shall be punched from low carbon steel sheet of 1.5 mm nominal thickness, to meet the required punching accuracy and filling factor.

The required magnetic properties of the steel sheet and the procedures for the magnetic measurements, which will be carried out by CERN, are defined in Appendix 1, together with some basic requirements on their geometric properties, based on CERN's experience.

The final geometrical and mechanical specifications of the steel sheets will be the entire responsibility of the manufacturer, who will also define, in agreement with the steel maker, the appropriate inspection methods.

These specifications must be submitted to CERN for approva before the corresponding contract is placed.

The external dimensions of the steel sheet must be chosen by the magnet manufacturer and will depend on the envisaged punching procedure and the number of laminations punched per sheet. They must allow a sufficient margin for accurate punching of the contour and for the removal of undesirable wedge-shaped regions at the edges. Margins of 30 mm on the sides parallel to the rolling direction and of 15 mm on the other sides have been found to be adequate.

The supplier of the steel has to obtain CERN's approval. Prior to this approval, the proposed steel supplier must deliver to CERN samples of the proposed steel, which will be measured magnetically at CERN. This is not necessary in the case where the proposed supplier has previously delivered steel samples to CERN with satisfactory magnetic characteristics, according to Appendix 1. A list of steel makers who have already done so is given in Appendix 2.

2.2 Punching of the laminations

The dimensions of the laminations and the required tolerances are shown in Fig. 1. The pole profile is not final; CERN will communicate the final one to the manufacturer within two months after the signing of the contract.

The punching procedure needed to obtain the specified accuracy is entirely the responsibility of the manufacturer; the following points must be observed:

- The pole profile, the mating surfaces and the reference surfaces must be punched in the same operation.
- The lamination burr must not exceed 0.06 mm. Any eventual deburring operation must damage neither the punched profile nor the insulating layer of the laminations.
- As the steel is very soft, special care must be taken to avoid distortion or damage to the laminations in handling, transport and storage. Any distorted lamination must be rejected.

Before the series production of the punched laminations can start, the dimensional tolerances must be checked in the presence of a CERN representative. This will be done by punching a number of laminations and measuring three of these. These tests will constitute the acceptance test of the die. The manufacturer must have adequate facilities for these measurements.

The manufacturer shall inspect laminations from the production runs frequently enough to monitor the performance of the die. After each re-sharpening of the die, three laminations shall be fully measured by the manufacturer and the results communicated to CERN. CERN reserves the right to take sample laminations for inspection every 5000 laminations and after each re-sharpening of the die. If any of these fail to meet the specified dimensions and tolerances, all laminations punched since the last accepted sample laminations may be rejected.

2.3 Insulation of the laminations

The laminations must be insulated with a continuous thin layer of inorganic insulating material, by a chemical treatment or preferably by blue steaming of the steel sheet.

The insulation quality shall be measured once for every quadrant on a stack of 20 laminations under a pressure of 1 N mm^{-2}. The resistance of this stack shall exceed 13.5 mΩ .

2.4 End plates

The stacks of punched laminations are terminated at both ends by 32 mm thick end plates. The contour of the end plates must stay inside that of the laminations and not differ from it by more than 0.1 mm on the pole and mating surfaces, and 0.5 mm on the rest of the contour, except when differently indicated in the drawings.

A number of holes will have to be drilled and tapped in the end plates (see Fig. 2) for the supports of electrical and water connections and for the supports of the vacuum chamber.

The end plates must be made from an annealed low-carbon steel, having a carbon content lower than 0.1 %.

The geometric and mechanical properties of this material are the responsibility of the manufacturer. The magnetic properties must comply wi the following specification:

- the values of coercivity for all end plates must remain within ± 20 A m^{-1} with respect to the nominal value, which shall be less than 160 A m^{-1},
- at a field of 24'000 A m^{-1}, the induction shall exceed 1.95 Tesla

To improve the field symmetry at low excitation levels, the eight end plates, which are necessary for a quadrupole, must be taken out of the same steel plate.

The magnetic properties of the end-plate steel will be checked by CERN on ring samples having the following dimensions:

inner diameter	:	76 ± 0.1 mm
outer diameter	:	114 ± 0.1 mm
thickness	:	12 ± 0.1 mm.

A sample per parent steel plate has to be delivered by the manufacturer; the production of the end plates can only start after the magnetic properties of the end-plate material have been approved by CERN.

2.5 Tension rods

In order to limit the outward bulging of the end plates under the action of tension and magnetic forces in the region of the pole, an M22 rod is inserted through each pole. The rods must be made of ST 60 steel and insulated from the magnetic circuit by means of a fibre-glass tube and washers.

2.6 Reinforcing profiles

The reinforcing profiles, bent out of 10 mm thick mild steel sheet, are welded all along the stack and to the end plates, to give the stack sufficient stiffness against torsion and sagging. It is likely that the profile sides will have to be machined to ensure that they properly match the lamination geometry.

Eight cylindrical supports of 20 mm diameter are welded on the upper profiles for fixing the alignment targets (for dimensional tolerances see Fig. 3). The U-shaped magnet feet are welded to the lower profiles. Four M8 holes are foreseen for fixing the protection covers on the magnet end where the electrical connections are located.

APPENDIX 1

1. MAGNETIC PROPERTIES OF THE STEEL SHEET

General

The quadrupoles will operate at an induction level in the iron comprised between 0.15 and 1.7 T. The steel must therefore have a low coercivity and high permeability. In view of the narrow spread in the magnetic characteristics of the quadrupoles to be achieved throughout their operating range, the uniformity of the magnetic properties of the steel sheet is important.

Type of steel

The experience gained in the construction of similar magnets at CERN indicates that the required magnetic characteristics can be obtained by the use of low-carbon steel with a low content of impurities and by a combination of suitable annealing treatments and cold reductions, which further reduce the carbon content and make the grain grow. The magnetic chacteristics indicated in this specification have actually been achieved in large scale industrial production for previous CERN projects.

Coercivity

The coercivity hereafter specified is the value of the magnetizing field which reduces the induction in the steel to zero from the value existing after excitation $H_{max} \geqslant 5000$ A m^{-1}. The values of coercivity for the whole steel delivery must remain within $\pm$ 12 A m^{-1} with respect to the nominal value, which shall be less than 65 A m^{-1}.

Permeability

The required values of permeability, i.e. the ratios of magnetic induction to the applied field measured at points along the curve of first magnetization, and their permissible spread are usually specified, for the purpose of magnet design, as a function of the induction.

In order to facilitate measurements, the following equivalent specification of the induction as a function of the field is given:

a) At a field of 40 A m^{-1}, all measured values of induction must be higher than 0.04 T.

b) At a field of 1200 A m^{-1}, all measured values of induction must be higher than 1.5 T, and their spread, i.e. the difference between the highest and the lowest value, must be less than 0.06 T.

c) At a field of 24'000 A m^{-1}, all measured values of induction must be higher than 2 T.

1.5 Ageing

In principle, the steel supply should be entirely stable with respect to time in both coercivity and permeability. Since the operating temperature of the magnets is expected not to exceed 30°C, stability of the magnetic properties refers to several years of operation at this temperature.

As a practical criterion, it is proposed that the ageing properties of the steel sheets are evaluated by remeasuring the coercivity after 100 hours accelerated ageing at 150°C on samples from full-scale production. The values on the aged samples should not exceed those measured before accelerated ageing by more than 10 A m^{-1}. It is not proposed to perform systematic ageing tests throughout the production, but is is expected that the constancy of the ageing properties will be ensured by the constancy of the chemical composition and by the reproducibility of the production process. Therefore, the results of the chemical analysis carried out by the steel maker on each batch of steel and the records of the processing shall be made available to CERN. The relevant tolerances should be proposed by the steel maker and agreed by CERN.

1.6 Procedure for the magnetic measurements

The magnetic properties of the steel will be tested by CERN by systematic measurements on samples taken throughout the delivery.

A sample, consisting of eight plates of dimensions 140 mm x 140 mm, will have to be taken from the beginning of each steel coil in its final condition.

Several samples will be taken from the first coils at different positions in order to assess the variation of the properties inside each coil and from coil to coil.

The precise total number of samples will be fixed once the number of steel batches and the size and number of the steel coils have been agreed between the manufacturer and the steel maker.

It may be expected that the number of samples required will be of the order of 600. A representative of CERN may be present for the choice and preparation of the samples.

The steel samples will be cut at the steel maker's plant to rings of 76 mm inner diameter and 114 mm outer diameter and sent to CERN for the measurement of their magnetic properties.

In order not to spoil the magnetic properties of the steel, the rings must be cut at low speed (e.g. on a lathe or by a special machine tool). Punching is not admissible.

No steel can be delivered to the manufacturer until the corresponding samples have been magnetically tested at CERN.

It is proposed that the results of the measurements by CERN shall be submitted to the steel maker. Unless an objection is made within fourteen days after receipt of the data, it will be assumed that the steel maker is in agreement with the results. Subsequently, these figures will be used for the purpose of acceptance and rejection. In the event of an irresolvable dispute about the results of the measurements, a neutral institution will be required to arbitrate.

Tolerances on magnetic characteristics measured on samples

It is desirable that from any steel batch no sample should show magnetic characteristics outside the limits stated in sections 1.3 to 1.5.

CERN reserves the right to refuse acceptance of a batch of steel which exhibits unsatisfactory magnetic characteristics.

2. GEOMETRICAL AND MECHANICAL PROPERTIES OF THE STEEL

The detailed specifications and the acceptance procedures will have to be established by the contractor and must be agreed upon by the steel maker, manufacturer and CERN.

General

In order to maintain constant magnetic characteristics, no mechanical processing of the steel sheets except shearing, punching and deburring can be permitted after the sampling for magnetic measurements.

As a general statement, it is required that the steel in its final condition be suitable for precision punching, and for assembling in straight stacks with a large packing factor.

2.2 Flatness

The sheets should be flat in order to permit a regular stacking of the laminations and to achieve the required stacking factor under a pressure not exceeding 2 N mm^{-2}.

Although the acceptance criteria and tests will be the responsibility of the contractor, the following limit, which is based on CERN experience, is suggested:

> When a sheet of dimensions 500 x 1000 mm^2 is laid on a marble, the distance from any point of the upper face to the marble must be smaller than 5.0 mm.

Thickness

The thickness of each individual steel sheet should be kept within ± 0.11 mm of the nominal value of 1.5 mm as measured at any point of the sheet.

The spread in thickness transverse to the rolling direction should be kept within ± 0.05 mm inside the region limited by two lateral strips of 10 mm width.

Mechanical properties and chemical composition

It can be expected that the steel sheets will have an elastic limit of about 100 to 150 N mm^{-2}, a tensile strength of about 200 to 250 N mm^{-2} and a hardness of about 80 HB. The chemical composition will be characterized by a very low content of impurities.